Effect of Inspiratory Time on PEF/PIF Ratio in Three Oscillating PEP Devices in an Adult Chronic Bronchitis Model

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Introduction

Oscillating positive expiratory pressure (OPEP) therapy is an airway clearance technique designed to help clear secretions from airways. One of the primary factors for effective secretion clearance is the ratio of peak expiratory flowrate (PEF) to peak inspiratory flowrate (PIF). It has been reported that in order to move mucus cephalad, the PEF must exceed PIF by 10% (PEF/PIF > 1.1), creating an expiratory flow bias.[1,2]

Flow bias refers to the overall net movement of gas flow based on inspiratory and expiratory flowrates. As an analogy, two steps forward and one step back would be overall net movement forward whereas two steps forward and three steps back would be overall net movement backward. Likewise, a higher peak inspiratory flow than peak expiratory flow generates an inspiratory flow bias and therefore net movement of gas flow to the lung periphery. A higher peak expiratory flow than peak inspiratory flow generates an expiratory flow bias and therefore net movement of gas flow toward the oropharynx.

The primary purpose of this study is to examine what effect various inspiratory times have on expiratory flow bias and the PEF/PIF ratio produced by three oscillating PEP devices during simulated breathing: the vPEP (D R Burton Healthcare, Farmville, NC), the Aerobika (Monaghan Medical, subsidiary of Trudell Medical International, London, Ontario Canada), and the Acapella (Smiths Medical, Kent, United Kingdom). Any differences in PEF/PIF ratio between the three devices will also be examined. The secondary purpose is to evaluate any differences in flow amplitude, mean expiratory pressure, and the absolute value of peak expiratory flow between the three devices. The primary hypothesis is that as inspiratory time is prolonged, it will cause an increase in the PEF/PIF ratio and therefore improve expiratory flow bias. The secondary hypothesis is that there will be no differences in the PEF/PIF ratio, flow amplitude, mean expiratory pressure, and the absolute value of peak expiratory flow between the three devices.

Method

An IngMar Medical ASL 5000 lung simulator, v.3.5 (Pittsburgh, PA) was used in the data acquisition and analysis. The instrument was programmed to simulate OPEP therapy in an adult chronic bronchitis patient with a lung compliance of 80 mL/cmH_2O and resistance of 30 cmH_2O/L/sec. Measurements were taken at four different inspiratory times: 1.33 seconds, 2 seconds, 4 seconds, and 6 seconds. A respiratory rate of 6 breaths per minute and a four-second, active exhalation was set for all measurements.

Inspiratory muscle pressure was adjusted to achieve a tidal volume of 1200 mL. The rationale for choosing this volume is based on two studies: a longitudinal study of COPD patients and another study of healthy volunteers. In the longitudinal study, 5,992 COPD patients were found to have a mean inspiratory capacity of 2.03 liters.[3] In the other study, forty-two healthy subjects performing OPEP therapy achieved approximately 65% of their inspiratory capacity when asked to take a deeper breath than normal.[4]

Therefore, applying the values in two studies and adjusting for disease process, it is reasonable that the average COPD patient would be able to achieve a volume of approximately 1200 mL when performing OPEP therapy. Additionally, some instructions for use indicate that a patient should inhale at 2-3 times greater than a normal breath, which would result in approximately the same tidal volume that was used in this study.[5]

Complete instrument settings are shown in Figure 1. To obtain the various inspiratory times and I:E ratios, the inspiratory rise time % and inspiratory release time % were adjusted as shown in Table 1.

Table 1. Inspiratory rise and release times associated with inspiratory times used in the study. Cycle time was ten seconds and expiratory time was set for four seconds.

	Inspiratory rise time %	Inspiratory release time %
1.33 second IT (1:3)	6.6	6.7
2.0 second IT (1:2)	10	10
4.0 second IT (1:1)	20	20
6.0 second IT (1.5:1)	30	30

The devices were placed in the horizontal position at the inlet of the simulator using 22 mm O.D. and I.D. adaptors (Figure 2). Measurements were taken at the lowest resistance setting and no measurement was taken until the volume reached a steady state (± 20 mL of target). After reaching the target volume, the simulator was allowed to run an additional five minutes before recording any data.

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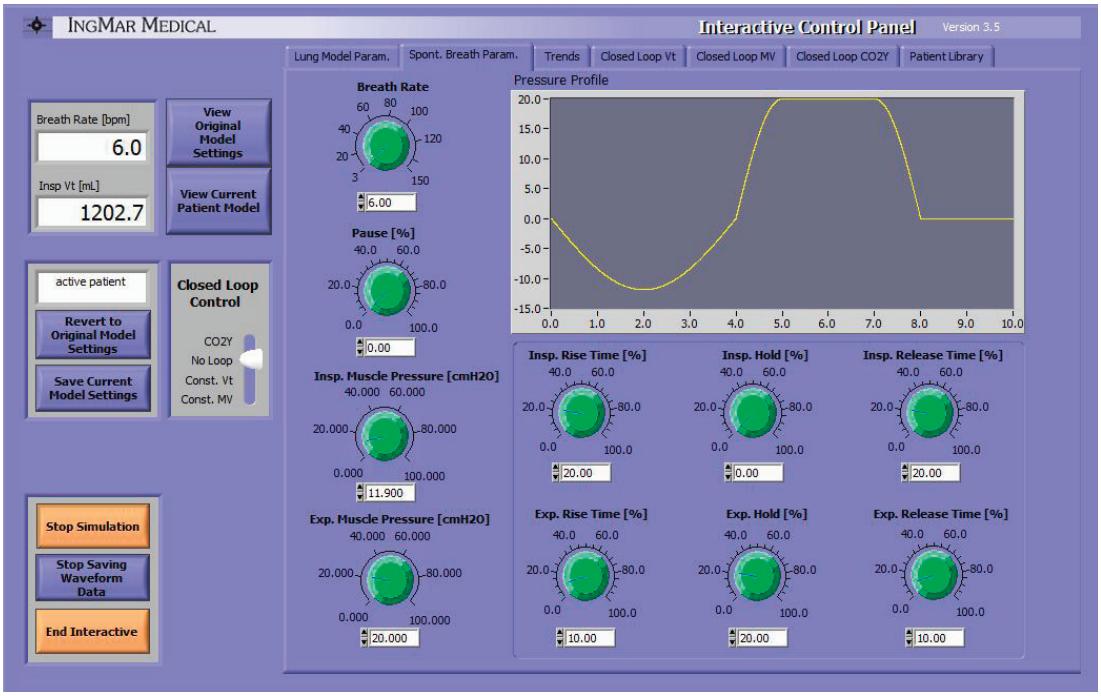
Figure 1. Screen capture of complete settings used in the study. Shown: inspiratory time of 4 seconds, expiratory time of 4 seconds, and resulting I:E ratio of 1:1.



Peak inspiratory and peak expiratory flows were measured and recorded from a scrolled reading on the flow-volume loop while mean expiratory pressure was recorded as a digital reading from real time analysis on the ASL 5000. Flow amplitude was measured and recorded from a scrolled reading at 25%, 50%, and 75% of expiratory volume on the flow-volume loop. The values were then averaged to get a mean value. The ratio of peak expiratory flow to peak inspiratory flow was also calculated and recorded. For all parameters, three separate measurements were taken to get a mean value. Statistical analysis was performed using SPSS software (Chicago, IL).

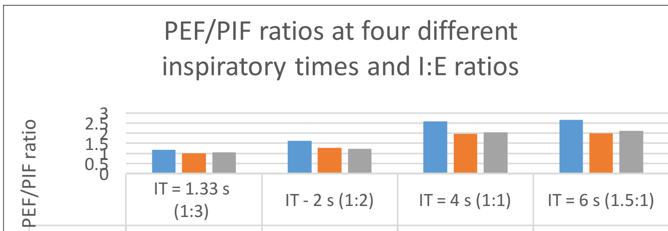
Figure 2. (L to R) Acapella, Aerobika, and vPEP attached to the IngMar ASL 5000 for performance testing

Results

PEF/PIF ratio

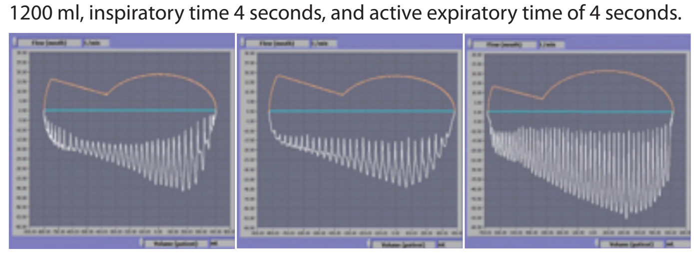
In all three devices, as inspiratory time was prolonged, there was an absolute increase in the PEF/PIF ratio (P <.001). The greatest mean percentage change in PEF/PIF occurred when inspiratory time was increased from 2 seconds to 4 seconds (58.3% increase) compared to the change from 1.33 to 2.0 seconds (28.7% increase) and the change from 4 to 6 seconds (2.7% increase). There were also statistically significant PEF/PIF ratio differences between all three devices (P < .001). The vPEP produced the highest mean PEF/PIF ratio across all four inspiratory times (2.02), followed by the Acapella (1.61) and the Aerobika (1.57). Chart 1 summarizes the PEF/PIF ratios for the three devices. Graph 1 shows representative flow-volume loops for the three devices captured at an inspiratory time of 4 seconds and expiratory time of 4 seconds (I:E 1:1).

Chart 1. PEF/PIF ratios at different inspiratory times and I:E ratios



	IT = 1.33 s (1:3)	IT - 2 s (1:2)	IT = 4 s (1:1)	IT = 6 s (1.5:1)
vPEP	1.18	1.63	2.59	2.66
Aerobika	1.01	1.29	1.96	2
Acapella	1.06	1.24	2.04	2.11

Graph 1. Representative flow-volume loops captured at a tidal volume of 1200 ml, inspiratory time 4 seconds, and active expiratory time of 4 seconds.



Absolute value of peak expiratory flow

Although the absolute value of PEF differed significantly between the three devices (P < .001), it did not vary significantly as the inspiratory time was increased from 1.33 to 6 seconds (P = .08). The specific inspiratory and expiratory flowrates for different inspiratory times are shown in Table 2.

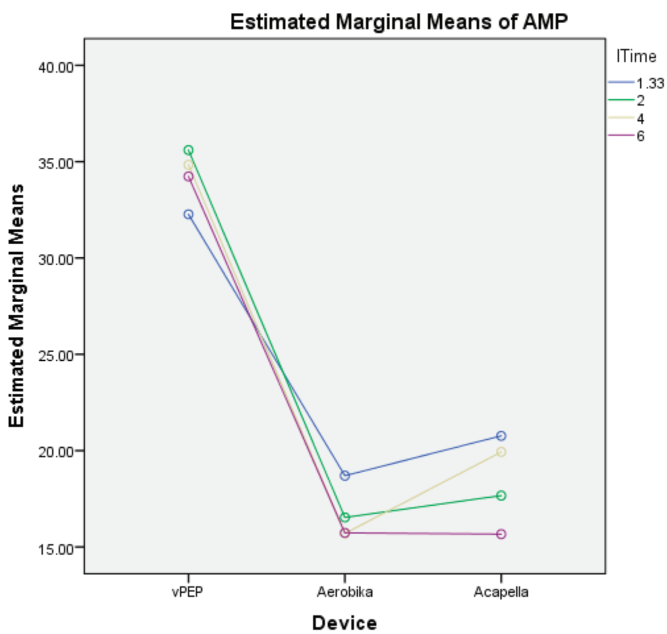
Table 2. Peak expiratory and peak inspiratory flowrates at four different inspiratory times

	vPEP			Aerobika			Acapella		
IT	PEF l/m	PIF l/m	PEF/PIF	PEF l/m	PIF l/m	PEF/PIF	PEF l/m	PIF l/m	PEF/PIF
1.33 s	55.6	47	1.18	41.7	41.2	1.01	41.5	39.3	1.06
2.0 s	56.8	34.8	1.63	39.8	30.8	1.29	40	32.3	1.24
4.0 s	56.6	21.9	2.59	38.9	19.9	1.96	42	20.6	2.04
6.0 s	56.3	21.1	2.66	39.6	18.9	2.0	41.2	19.7	2.11

Flow Amplitude

There were significant differences in flow amplitude between the three devices across all four inspiratory times ($P < .001$). These differences can be observed in Graph 1. The range of amplitude was 15.7 – 20.8 L/m for the Acapella, 15.7 – 18.7 L/m for the Aerobika, and 32.3 – 35.6 L/m for the vPEP. Chart 2 summarizes flow amplitude for the three devices.

Chart 2. Flow amplitude in liters per minute across four inspiratory times for the vPEP, Aerobika, and Acapella.



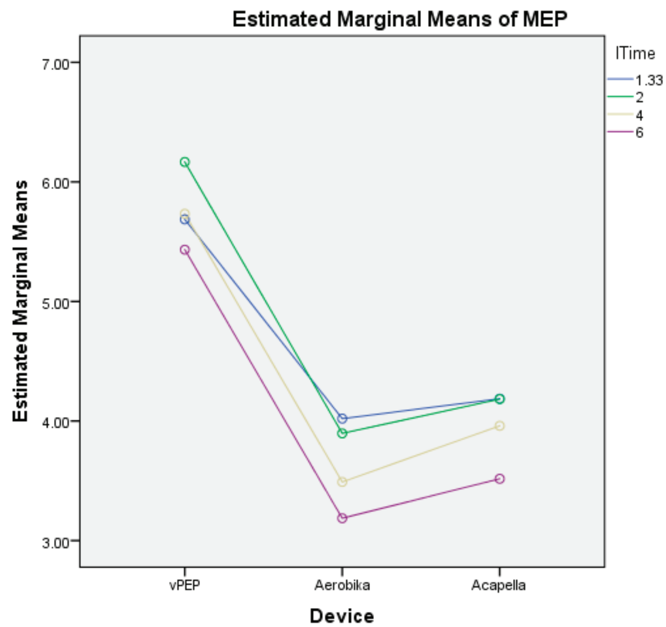
Mean Expiratory Pressure

There were significant differences in mean expiratory pressure between the three devices across all four inspiratory times ($P < .001$). The range of mean expiratory pressure was 3.5 – 4.2 cmH_2O for the Acapella, 3.2 – 4.0 cmH_2O for the Aerobika, and 5.4 – 6.2 cmH_2O for the vPEP. Chart 3 summarizes mean expiratory pressure for the three devices.

Discussion

The performance measures in this study — the PEF/PIF ratio, flow amplitude, and mean expiratory pressure — were chosen because collectively these measures represent the primary mechanisms of action for airway clearance devices. The PEF/PIF ratio determines the degree of expiratory flow bias, which is important in driving airway secretions cephalad. The flow amplitude (along with the frequency) determines the quality of oscillations, which would theoretically indicate the degree to which a device reduces the viscosity of mucus. And finally the mean expiratory pressure, which augments the functional residual capacity, is important in moving air behind obstructions through collateral ventilation channels.

Chart 3. Mean expiratory pressure in cmH_2O across four inspiratory times for the vPEP, Aerobika, and Acapella.



Expiratory flow bias is imperative in oscillating PEP therapy and is highlighted as the main finding of the study. As inspiratory time was prolonged, the PEF/PIF ratio and therefore expiratory flow bias improved in all three devices. The greatest increase was seen when the inspiratory time was lengthened from two seconds to four seconds. This is interesting because in the study of 42 healthy volunteers mentioned earlier[4], the mean inspiratory time during OPEP therapy (excluding the breath hold) was 2.02 seconds, indicating that subjects and presumably patients have a tendency to inspire too quickly.

Continuing on this line, because PEP and OPEP devices sometimes share the same instructions for use, it might be assumed they share the same mechanical characteristics. In actuality, PEP and OPEP devices differ in their ability to produce mean expiratory pressure and expiratory flow bias. PEP devices tend to produce greater resistance, which increases mean expiratory pressure, but decreases peak expiratory flow and therefore expiratory flow bias.

Given these circumstances, instead of focusing exclusively on the pressure created by an OPEP device, an alternative approach might be to put emphasis on the PEF/PIF ratios and the expiratory flow bias they produce. Keep in mind that just as in a cough, it is actually short bursts of increased expiratory air flow that help move secretions up the airway.[6]

Ntoumenopoulos et al, looked at flow bias by comparing peak inspiratory and expiratory flowrates in twenty intubated and ventilated adult patients.[7] They found that commonly used ventilator settings produced an inspiratory flow bias in 19 of 20 patients, which would theoretically cause secretion retention. In the same issue, an editorial by Volpe and Amato asks the question, "Is it time to monitor flow bias during mechanical ventilation?"[8] Their takeaway was that an inspiratory flow bias might be beneficial in conditions such as early ARDS, but also that it might be advantageous to create a "temporary" expiratory flow bias to optimize secretion clearance therapy in paralyzed patients or those with an ineffective cough.

Bennett and colleagues studied the effect of inspiratory time on expiratory flow bias (EFB) generated by manual hyperinflation in a bench model.[9] They concluded that when using manual hyperinflation to aid in mucus clearance, inspiratory times of at least three seconds for normal compliant lungs and two seconds for less compliant lungs appear necessary to achieve an EFB in their bench model.

Finally, an animal study by Bassi et al also looked at flow bias and mucus clearance.[10] In this study, inspiratory and expiratory flowrates were monitored in eight healthy pigs being mechanically ventilated. Movement of mucus was then assessed fluoroscopically at six different duty cycles or I:E ratios. Radiopaque markers were employed to determine mucus velocity. They concluded that mucus clearance improved with prolongation of the inspiratory time.

Conclusion

The primary hypothesis of the study was supported and found that assuming a constant expiratory time, the PEF/PIF ratio increased as inspiration was prolonged. Specifically, that a slow, four-second inspiration combined with a steady four-second active exhalation (I:E ratio of 1:1) produced a greater PEF/PIF ratio compared to shorter inspiratory times of two seconds or less. With this in mind, it may be time to reevaluate the time-honored 1:3 or 1:4 I:E ratio that is commonly associated with oscillating PEP therapy. The importance of instructing a patient to perform a slow, prolonged inspiration during oscillating PEP therapy cannot be overstated and is integral in order to achieve the greatest possible expiratory flow bias.

The secondary hypothesis was rejected because the study found there were significant differences in the PEF/PIF ratio, absolute value of peak expiratory flow, mean expiratory pressure, and flow amplitude between the three devices as previously outlined. More work is needed in order to determine if these differences affect outcomes in COPD or other patient populations.

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